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LOWLAND BIRD INVENTORY
HAWAI`I VOLCANOES NATIONAL PARK

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ABSTRACT

The objectives of this survey for lowland birds in Hawai`i Volcanoes National Park (HAVO) were to (1) document at least 90% of bird species present, (2) estimate relative abundance and distribution of species, and (3) establish baseline information to use for future monitoring in the park. Results were derived from both area search and line transect methodologies. Counts were conducted on 25 days between 14 April and 14 July 2005. Our diversity index indicates that the HAVO lowland bird assemblage is relatively diverse and comprised of 25 species, including nine natives and 16 non-natives. We observed more than 80% of the bird species expected to inhabit lowland areas of HAVO. Most species, including both native and non-natives, were relatively rare and were observed at only a few sites or transects. No federally listed endangered species were detected during our surveys. Extra search effort was given to detect the introduced Close-barred Francolin (*Francolinus adspersus*), but we conclude that the species, once found in the park, is no longer present. We documented the presence of two species new to HAVO, the Yellow-billed Cardinal (*Paroaria capitata*) and Yellow-fronted Canary (*Serinus mozambicus*). We make recommendations of sampling effort for future monitoring of the lowland bird community in HAVO.

INTRODUCTION

The Biological Inventories Project of the National Park Service Inventory & Monitoring program (NPS; I&M) sponsored the Lowland Bird Inventory of Hawai`i Volcanoes National Park (HAVO). The NPS I&M program has prioritized the following three objectives to scientifically inventory and document park vertebrate biodiversity: (1) document at least 90% of vertebrate and vascular plant species within park boundaries through existing data and targeted field surveys, (2) demonstrate relative abundance and distribution of species of concern, including T&E species, aliens, and species of management interest; and (3) establish baseline information to develop a monitoring plan for the park.

In this report, we summarize surveys conducted to inventory birds in lowland HAVO (regions of the park < 1,200 m elevation; I&M is conducting additional research on plants to complete objective 1). The bird habitat of the HAVO lowlands constitutes a vast mosaic of successional plant communities across a steep gradient of rainfall, extending from rainforest in the northeast, through shrublands and woodlands, to sparsely vegetated desert-like conditions in the southwest. Periodic lava flows and fires maintain the successional mosaic. This study covered open habitats and human development on all of Kīlauea Volcano within the park, excluding only rainforest.

Past surveys (Baldwin 1941; Banko and Banko 1979) have shown that bird populations in the park lowlands exist at very sparse densities, probably only a few birds/km^2 over broad areas. Exceptions include areas where birds are attracted to human activity (e.g., office and maintenance facilities, picnic and camping areas, and interpretive waysides). Anchialine pools along the coast, which are sources of standing fresh and brackish water, may attract birds. Sites of human activity and anchialine pools may both serve as colonization sites for alien species new to the park.

Lastly, one non-native species of partridge, the Close-barred Francolin (*Francolinus adspersus*), has been shown to occur exclusively at HAVO within the entire Pacific Island Network (PACN) park system, and here only in the vicinity of the historic `Āinahou Ranch headquarters. This species has not been reported with certainty for the past decade although there have been several anecdotal observations within the last five years. Therefore, we sought to determine if the species is extant in the park. To survey and quantify these very different bird communities, and the one rare partridge, we sampled birds using two sampling methods, area search and line transect, each aimed to inventory avian species diversity and abundance in park lowlands.

METHODS

The HAVO Lowland Bird Inventory was conducted between 14 April and 14 July, 2005. This study was limited to the non-forested areas in the lowland regions of the park. The survey was conducted by Kathryn Turner and Roberta Swift, I&M cooperators with the Hawaii-Pacific Islands Cooperative Ecosystems Studies Unit. Both observers listened to tapes of bird vocalizations, and calibrated distance measures before conducting surveys. Statistical analysis was performed and the report co-written by Richard Camp, Project Coordinator, Hawai`i Cooperative Studies Unit (HCSU), and the project was conceived and the report reviewed by Thane Pratt, Wildlife Biologist, US Geological Survey (USGS).

Sampling Methods

Birds were surveyed using two different methods, depending on location: area searches (AS) at areas expected to attract birds and line transect (LT) along trails. Area searches are used for surveying birds in specifically designated areas, sites expected to attract birds, for a specified duration. In AS sampling, the surveyor walks throughout a set area searching for birds for a set amount of time (Bibby et al. 2000). Line transects are ideal for collecting data in open areas. The observer walks along transects and records the distance and sighting angle from the transect centerline to the bird (Bibby et al. 2000). A critical assumption of LT sampling is that all birds on the transect centerline are detected. Thus, birds distant from the transect centerline may be missed, and the proportion missed increases with increasing distance.

Area Search Survey

Area search surveys were conducted at 38 points of human use and at anchialine pools in HAVO. These sites consisted of parking lots, pullovers, beaches, human impacted areas, and anchialine pools in the park (Figure 1; see Appendix A for representative photos and Appendix B for site characteristics). Intensity of human use and alteration is described in Table 1. These sites are thought to serve as colonization sites for alien species new to the park. At each site, a one-ha plot was established with a GPS unit and rangefinder. The data recorded for each site were date, start and end time, bird species, and number of individuals. Observers walked through the survey area, counting as many birds as possible while quantifying the time spent. The ideal amount of time spent to survey the one-ha area was 15 minutes (Bibby et al. 2000). The range of time spent surveying sites was 10-32 minutes (mean = 16.7 minutes, standard deviation = 4.6 minutes).

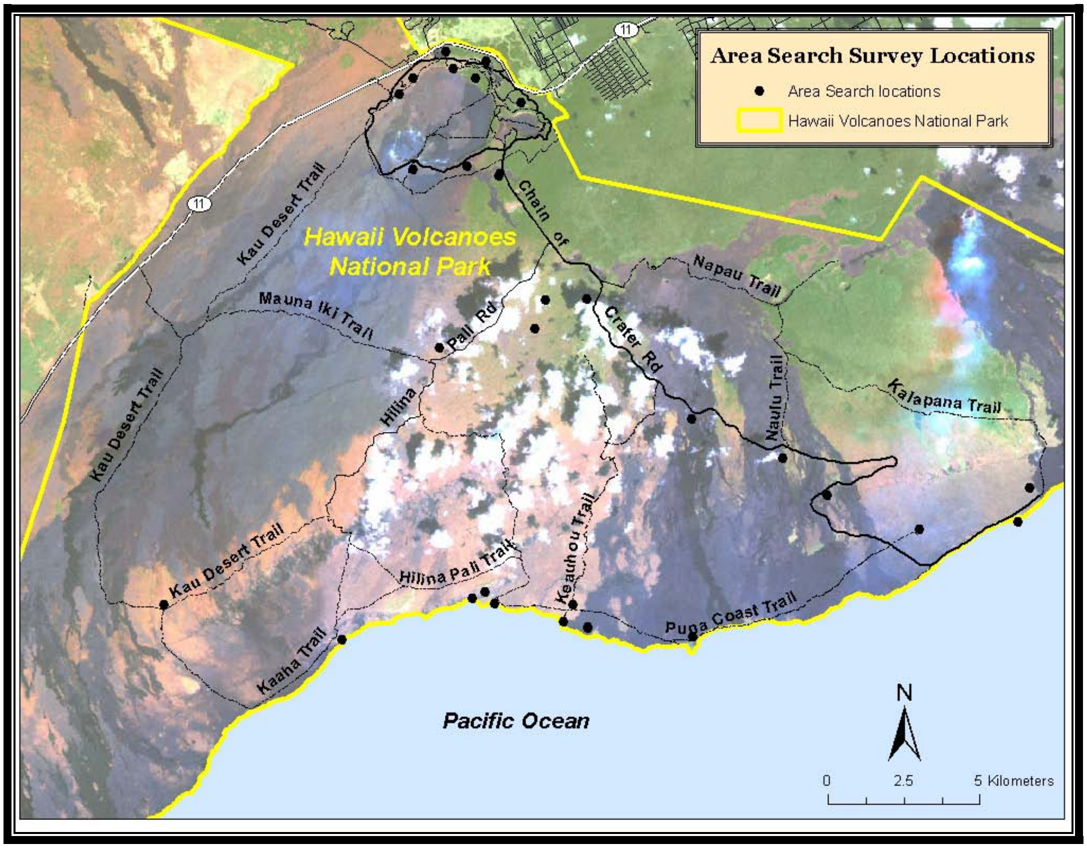

Figure 1. Sites (black dots; 30 dots represent 38 sites) surveyed using area search survey methods, Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.

***Table 1.** Definitions of the use and alteration levels assigned to area search survey sites, Hawai`i Volcanoes National Park, 14 April -14 July, 2005.*

Use	Definition
Intensely used or altered sites	Areas that are visited frequently or the habitat has been significantly altered (e.g., lawns).
Moderately used or received limited alteration sites	Areas that are regularly visited and have minor development to facilitate visitation (e.g., habitat mostly intact but pullouts and trails exist).
Unaltered or rarely used sites	Areas that are visited infrequently and where the habitat has not been altered.

Line Transect Survey

Due to issues of safety and accessibility, existing trails were chosen as transects instead of establishing a new grid of transects. Trails were systematically divided into one-km transects with 250-m breaks separating transects (Figure 2). The trails were assigned to one of three habitat types: woodland, shrubland/ grassland, and barren lava following the Jacobi (1989) classification system (See Appendix C for representative photos). Thirteen trails were surveyed with varying numbers of transects per trail, ranging from one to 22 transects per trail (Table 2; see Appendix D for transect characteristics). Line transect surveys were conducted on 84 transects from 119.8 km of trails. We randomly selected the location of the beginning of the first transect of each trail using a random number table, by 100-m intervals, up to one-km from the trail head. Distance was estimated to birds within 300 m of the transect centerline using rangefinders. We slowly walked (one kilometer every 30 minutes) along the one-km transect and listened and scanned the surrounding area for birds using binoculars (8x32). At the beginning and end of each transect, the date, observer, transect route, and sampling conditions were recorded, and a photo was taken (see Appendix E for definitions). When a bird was detected, either by visual or audio detection, we stopped and recorded the time of detection, species, number of individuals, sex, detection type, distance from observer, azimuth of transect, azimuth to bird, waypoint, whether the bird was disturbed by observer, flyover, and direction of flight (see Appendix E for definitions).

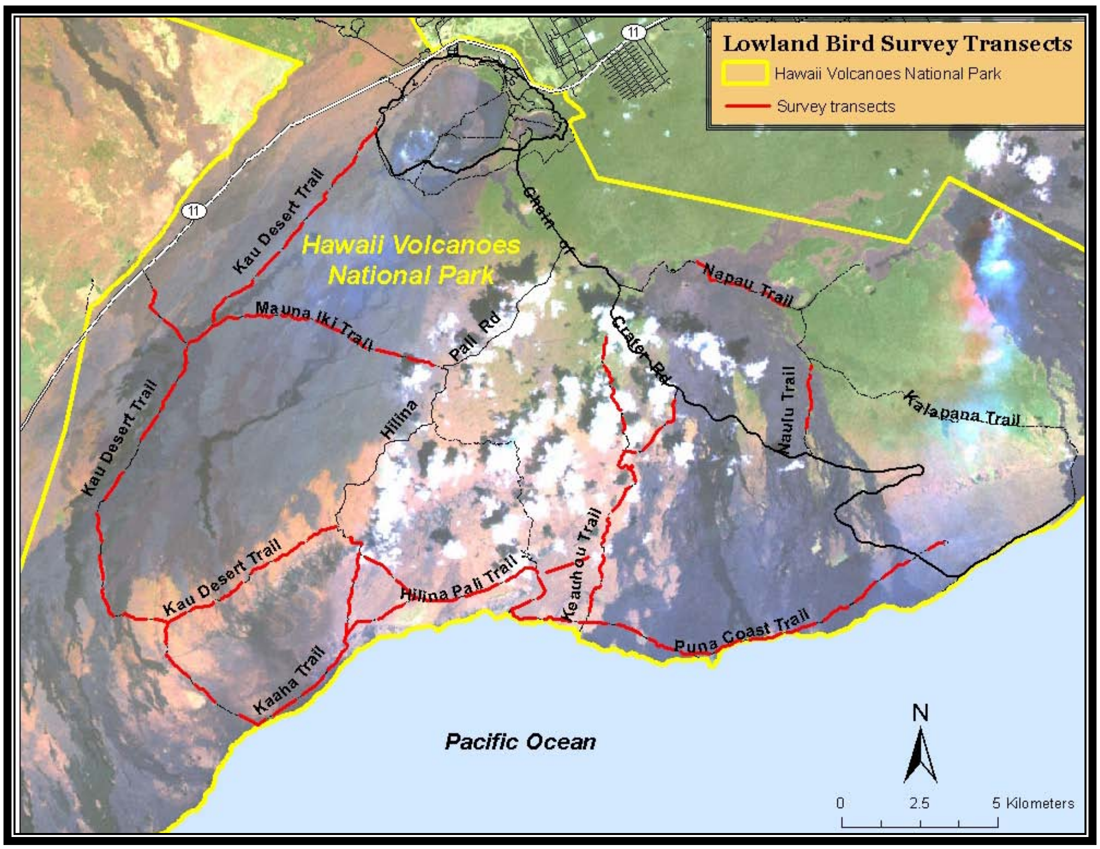

Figure 2. Transects (in red) surveyed using the line transect survey methods, Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.

Table 2. *Trails surveyed using the line transect survey methods, Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.*

Trail	Length (km)	Habitat Type[a]	Elevation Range (m)	Num. of 1-km Transects	Park Areas of Interest
Ka`ū Desert	33.3	W,S,B	512-1243	24	Footprints, Pepeiao Cabin
Puna Coast	18.2	S,B	0-52	12	Halapē, Keauhou, `Āpua Beaches
Keauhou	10.9	W,S	0-817	9	Keauhou Beach, Shelter
Mauna Iki	10.1	S,B	910-960	7	Twin Pit Craters
`Āinahou	5.0	W,S	750-972	4	Ranch House, Corral, Nene Pens
Ka`aha	9.7	W,S	0-512	7	Ka`aha Bay, Pepeiao Cabin
Nāpau	11.2	W,B	823-975	3	Makaopuhi Crater, Nāpau Crater
Nāulu	5.1	W,B	580-800	3	Makaopuhi Crater
Pu`uloa	1.5	S	50-57	1	Petroglyphs
Hilina Pali Triangle	14.8	S	70-695	14	N/A

[a]Habitat type (W-woodland, S-shrubland/ grassland, B-barren lava) was assigned to each transect and summarized by trail.

Focal Partridge Search

An extensive AS was conducted at `Āinahou Ranch to look for a non-native species of partridge, the Close-barred Francolin. For four days and one evening, 24 and 31 May, 7 and 13 June 2005, we conducted a modified form of the AS method, looking in areas that would seem favorable habitat for the francolin (Appendix A). Searching the site followed the AS sampling methods, but we conducted the survey for 30-45 minutes and searched eight two-ha plots. We also conducted a LT survey on four one-km transects of the `Āinahou Trail on 7 and 8 June, 2005.

We calculated the detection probability, *p*, of the Close-barred Francolin assuming a randomly distributed population as

$$p = 1 - \left(1 - \frac{a}{A}\right)^{n}.$$

The effective search area, *a*, is the product of the effective detection distance (*EDD*) and the search area, *L*, using equation $a = 2 * EDD * L$ (Reynolds and Snetsinger 2001). We were unable to calculate the *EDD* directly for Close-barred Francolin; therefore, we used the *EDD* for Erckel's Francolin (*Francolinus erckelii)*, a species with similar habitat preferences (Scott et al. 1986). Our search effort equaled 4.8 km (*L*=4.8 km; four one-km LT and eight two-ha [=0.8 km] AS sites). We estimated the last known range of the Close-barred Francolin, *A*, to be 12 km^2, which includes all of the grassland at `Āinahou Ranch and some open woodland habitat. The total population size, *n*, we hypothesized to be 10 birds.

In addition, we calculated the minimum number of visits, N_{min}, needed to ensure a 99% extinction probability (Reed 1996) using the equation

$$N_{\min} = \frac{\ln(\alpha - level)}{\ln(1-p)},$$

where $\alpha - level = 0.01$, and p is the detection probability from above. We define a visit as four hours of search effort under good sampling conditions. That is, the amount of time required to survey four two-ha AS plots (30-45 minutes sampling per hectare) and four one-km LT transects (30 minutes sampling per one kilometer).

Data Analysis

All data were entered into a Microsoft Access 2000 database (NPS, I&M; Lowland Bird Inventory Database). For quality assurance all data entries were proofed and errors corrected. Summary analyses, including survey effort, species list, number of birds observed, frequency of detection (birds per site and birds per transect), and relative abundance (birds per site occupied and birds per transect occupied), were calculated for the inventory.

Species Richness, Diversity and Evenness

We used the Jackknife method of Heltshe and Forrester (1983a; see Krebs 1989) to estimate species richness for AS and LT surveys independently using program Ecological Methodology (2000). This method allowed us to calculate the number of species expected, with confidence intervals, and provided an indication of the number of species we may have missed during our inventory. The jackknife estimator tends to overestimate the number of species in a community (Heltshe and Forrester 1983b; see Krebs 1989); thus, we expect to observe a greater proportion of the number of species than predicted.

Species diversity (observed heterogeneity in the number of individuals observed by species) was calculated using program Ecological Methodology (2000) from the Brillouin diversity index

$$H = \frac{1}{N}\log\left(\frac{N!}{n_1!n_2!n_3!\ldots}\right),$$

where N is the total number of individuals observed and n_i is the number of individuals belonging to the ith species. The Brillouin index was used because sites were not randomly selected from a large pool of possible sites, and we assumed are a finite collection sampled without replacement (Pielou 1966; see Krebs 1989). Similar to the Shannon-Wiener function, the Brillouin index usually does not exceed 5.0 (Krebs 1989), indicating a heterogeneous community. Values approaching zero indicate little heterogeneity in the community. Species evenness (equitability in numbers observed among species) for the Brillouin diversity index uses the Simpson measure (see Krebs 1989) and was calculated using program Ecological Methodology (2000). The Simpson measure scales the minimum diversity index relative to its maximal value, thus values range from 0 to 1.

We conducted inventories using sampling methods that allow for calculating detection probabilities. Accounting for species detection probabilities facilitates long-term population monitoring and the direct comparison of temporal measures (see Anderson 2001; Rosenstock et al. 2001; Bart 2005; and citations therein). More specifically, the proportion area occupied analysis yields frequency of occurrence estimates adjusted for detection probability, instead of producing naive proportion of sites occupied (see MacKenzie et al. 2002, 2003). Likewise, distance sampling techniques yield density estimates also adjusted for detection probabilities, and are used instead of relative abundance measures (see Buckland et al. 2001).

Distribution

We ascertained if differences exist between use categories of AS surveys, and habitat types of LT surveys, independently, using one-way analysis of variance tests (ANOVA). Using count data (numbers of birds) from AS surveys we tested the distribution of species that occurred at >20% sites by use category. Following similar methods, count data from LT surveys were assessed for distribution differences for species that occurred at >20% of transects by habitat type. We assumed the data were normally distributed for both ANOVAs, although this assumption was not tested because of small sample size.

A large number of AS sites (38 sites) and LT transects (84 km) were surveyed; however, the number of sites and transects were not balanced among the "intensity use" and "habitat" categories (see Appendices B and D). More specifically, only three unaltered AS sites and seven transects of woodland habitat were surveyed. This has implications for distribution analyses in that the ANOVAs were severely unbalanced. We expect an unbalanced design to obscure differences in distribution; however, this should not bias the distribution for species that were distributed differently (House Finch [*Carpodacus mexicanus*] and Japanese White-eye [*Zosterops japonicus*] for LT surveys).

Site Occupancy

Using program PRESENCE (http://www.proteus.co.nz), we determined the percent area occupied (PAO) for species at one site, Jagger Museum, which was sampled on three occasions. Jagger Museum was chosen because it was an intensely used site located in woodland habitat, and because several native and non-native species were present. Detection and non-detection data, by species, was input for each occasion, and modeled, without covariates, assuming that the state of occupancy is closed for the three occasions (single season model). That is, the site does not become occupied or abandoned by a species for the duration of sampling (MacKenzie et al. 2002) and the detection probability is assumed to be constant across survey occasions.

Density

We estimated densities (birds/ha) for species with adequate sample sizes (House Finch, Japanese White-eye, and Hawai`i `Amakihi [*Hemignathus virens*]). Using the program DISTANCE 4.0, post-stratified density estimates by habitat were determined using the global detection function and variation in density. Confidence intervals were determined using bootstrap methods following standard analytical methods described by Buckland et al. (2001, 2004), Burnham and Anderson (2002) and Thomas et al. (2002).

Density estimates were calculated for each habitat type using a global detection function and post-stratification options because the numbers of observations were small (< 50 detections per strata; Thomas et al. 2002). We did not account for covariates due to the small sample size (e.g., observer, weather conditions, etc.). Model selection for determining detection functions was restricted *a priori* to half-normal, hazard-rate, and uniform functions with expansions series of two orders. The sighting angle was calculated as the difference between the bird sighting azimuth and the transect azimuth. Detection histograms and associated statistics for each species were compared with untruncated data, 10-percent truncation, and g(x)=0.10 truncation to select 'best-fit' models (Buckland et al. 2001; Burnham and Anderson 2002; Thomas et al. 2002).

Monitoring requires precise measures of density to detect biologically relevant trends within short time spans. Data from our LT survey can be used to estimate the species specific total transect length (L_t) needed to produce density estimates with coefficient of variation (CV) values of 10%, 20%, and 50% following methods described by Buckland et al. (2001) with equation 7.5

$$L_t = \frac{L_o \left\{CV_o\left(\hat{D}\right)\right\}^2}{\left\{CV_t\left(\hat{D}\right)\right\}^2}.$$

Where L_o is the habitat specific transect length of our study (barren = 24 km; shrubland/grassland = 47 km; woodland = 13 km), and $CV_o\left(\hat{D}\right)$ is the coefficient of variation for the species-specific density estimate.

We recognize that the LT surveys were conducted along existing trails; therefore, our inference to areas not surveyed is limited. We do believe, however, that our distribution and density estimates are applicable to areas not surveyed, although with an unknown bias.

RESULTS

Survey Summary

Results for lowland birds in HAVO were derived from two survey methods, area searches (AS) and line transects (LT), conducted on 25 days between 14 April and 14 July 2005. A total of 25 bird species was detected during our surveys (Table 3). Frequency of detections varied by species and between our survey methods. For all species, however, the frequency of detections was relatively low, with less than half of sites or transects occupied. Similarly, relative abundance was quite variable (range 1-15 for AS sites, and 1-9 for LT transects).

Species Richness

The estimated species richness of AS sites was 27.9 species (95% CI: 23.7 – 32.0) of which we observed 23 species (82% of predicted species). The estimated species richness of LT transects was lower, 21.0 species (95% CI 17.6 – 24.3), and was derived from 18 observed species (86% of predicted species). See Appendix F for a list of possible species.

Diversity and Evenness

Species diversity, as measured by Brillouin's diversity, was H=3.5 for the 23 species observed among AS sites. Heterogeneity among the sites was slightly greater than one-half the possible range, indicating that the lowland bird community is relatively diverse. In fact, we observed 26% of the species found on Hawai`i Island. (23 of 87 species; Appendix F). The evenness measure was slightly less than one-half the possible range (Simpson measure $1/D$=0.42). This is indicative of a community with many species frequently observed, many species that were rarely observed, and a few species lying between these extremes (Figure 3); although we expect this value overestimated the true evenness measure (all evenness measures assume the total number of species in the whole community are known, and the estimator is biased since the observed number of species is less than the true number of species; see Krebs 1989:367).

Brillouin's diversity for LT data was H=2.9 for 18 species observed on the 84 transects. Similar to the AS diversity, a few species were observed frequently (4 species; >45 observations), a majority of species were observed rarely (11 species; <15 observations) and 3 species observed between these extremes (<45 x >15 observed) (Figure 3). In addition, the evenness measure was about one-third the possible range (Simpson measure $1/D$=0.32) and equivalent to the AS results.

Table 3. Species detected during area search and line transect surveys, Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.

Common Name	No. AS Sites Occ.	No. Detected	Freq Detections[a]	Rel. Abund.[b]	Intensity[c]	No. LT Transects Occ.	No. Detected	Freq Detections[a]	Rel. Abund.[b]	Habitat Types[c]
White-tailed Tropicbird	0	0	--	--	--	9	15	11	1.67	B,S,W
Hawaiian Goose	3	13	8	4.33	U,M,I	4	16	5	4.00	W
Erckel's Francolin	2	2	5	1.00	U	3	4	4	1.33	S,W
Kalij Pheasant	1	2	3	2.00	I	2	3	2	1.50	W
Pacific Golden-plover	5	9	13	1.80	U,I	5	14	6	2.80	B,S,W
Wandering Tattler	5	7	13	1.40	U	0	0	--	--	--
Ruddy Turnstone	1	1	3	1.00	U	0	0	--	--	--
Black Noddy	1	7	3	7.00	M	1	1	1	1.00	S
Spotted Dove	4	5	11	1.25	I	0	0	--	--	--
Zebra Dove	5	8	13	1.60	U,I	5	7	6	1.40	B,S
Barn Owl	0	0	--	--	--	1	1	1	1.00	S
Sky Lark	2	3	5	1.50	I	3	4	4	1.33	B,S
`Oma`o	2	2	5	1.00	U	1	1	1	1.00	B
Hwamei	1	1	3	1.00	M	3	5	4	1.67	S,W
Japanese White-eye*†‡	15	66	39	4.40	U,M,I	22	122	26	5.55	B,S,W
Common Myna*	14	35	37	2.50	U,M,I	16	49	19	3.06	B,S,W
Saffron Finch	3	10	8	3.33	I	0	0	--	--	--
Yellow-billed Cardinal	2	2	5	1.00	U	0	0	--	--	--
Northern Cardinal	2	3	5	1.50	M	8	14	10	1.75	S,W
House Finch*†‡	9	45	0.24	5.00	M,I	35	150	0.42	4.29	B,S,W
Yellow-fronted Canary	1	1	0.03	1.00	I	0	0	--	--	--
Hawai`i `Amakihi*‡	8	41	0.21	5.13	U,M,I	9	80	0.11	8.89	S,W
Apapane	6	24	0.16	4.00	U,M,I	3	13	0.04	4.33	B,W
House Sparrow*	8	55	0.21	6.88	I	0	0	--	--	--
Nutmeg Manikin	3	45	0.08	15.00	I	7	32	0.08	4.57	B,S

[a] Number of sites occupied/38 sites; number of transects occupied/84 transects.
[b] Number detections/number of sites occupied; number detections/number of transects occupied.
[c] Use intensity: I-intense, M-moderate, U-unaltered.
* Species with a * were tested for their spatial distribution across sites.
† Species with a † were tested for distribution among habitat types.
‡ Species with a ‡ were calculated for density estimates.

Distribution

Area Search

Hawai`i `Amakihi was the only native species observed at more than 20% of the sites (21%; Table 3). Japanese White-eye and Common Myna (*Acridotheres tristis*) were observed at more than 30% of the sites, and House Finch and House Sparrow (*Passer domesticus*) were observed at more than 20% of the sites (Table 3). The most common species were not distributed differently among AS intensity categories (Japanese White-eye P=0.62; Common Myna P=0.45; House Finch P=0.14; Hawai`i `Amakihi P=0.59; House Sparrow P=0.08). Thus, we found no indication that intensity of human use and alteration of AS sites influences the distribution of the common species.

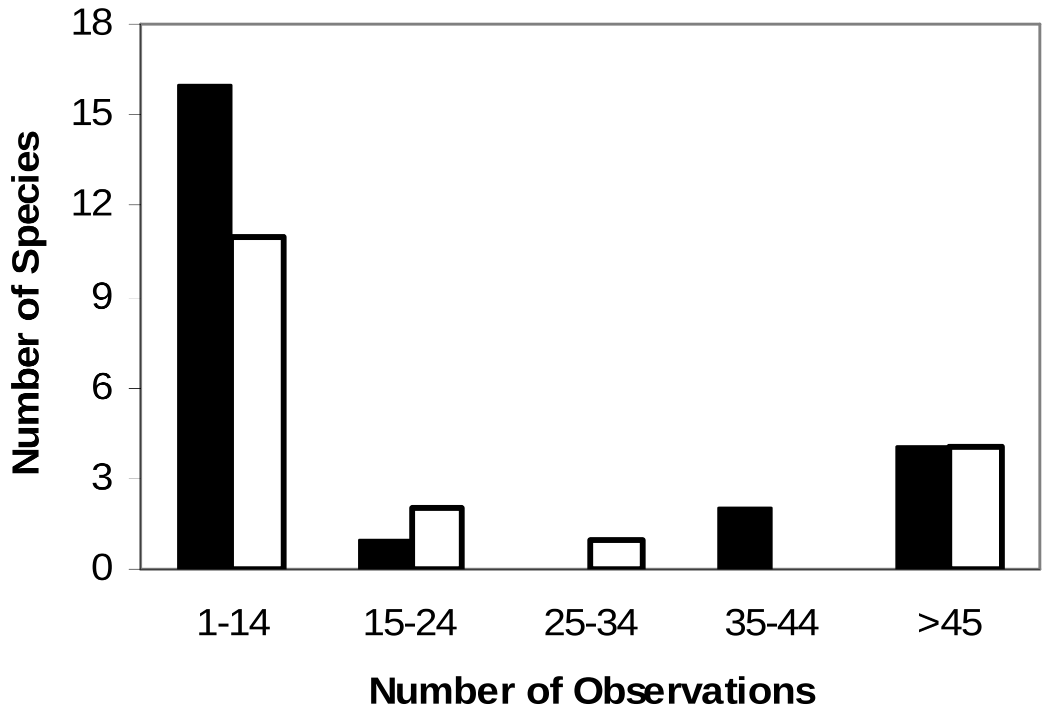

Figure 3. Comparison of number of observations for area search surveys (solid bars) and line transect surveys (open bars) by species**,** Hawai`i Volcanoes National Park, 14 April - 14 July, 2005. For both survey types many species were either rarely or frequently observed (<15 and >45, respectively), while a few species were observed between these extremes.

Line Transect

Native bird species were predominantly observed in woodland habitats, except for Pacific Golden-plover (*Pluvialis fulva*), which were observed along the Ka`aha and Puna Coast trails in shrubland/ grassland habitat (Figure 4). The most widely observed native species were Hawai`i `Amakihi and White-tailed Tropicbird (*Phaethon lepturus*); observed on 10% of transects (nine of 84 transects). In contrast, alien species were observed in all three habitat types (Table 3). About one-third of transects in barren and shrubland habitats were devoid of birds (36 and 37%, respectively). Only two species, House Finch (observed on 35 transects) and Japanese White-eye (observed on 22 transects) were observed on sufficient transects to warrant distribution analyses. Both species were most prevalent in woodland habitats (mean number of observations = 4.6 and 9.3, respectively), followed by shrubland (mean = 2.1 and 1.0, respectively) and barren habitats (mean = 0.6 and 0.2, respectively; P=0.003 and P<0.001, respectively).

Site Occupancy

Repeated sampling at a site makes it possible to estimate species' detection probabilities for determining percent area occupied. We observed six species on one or more occasions (n=3) at Jagger Museum. Jagger Museum is an intensely altered and frequently visited attraction site with sparse grass and shrubs surrounding multiple buildings and structures, paved parking lot and viewing areas, and a dense copse of mature `ōhi`a trees with a thick understory. MacKenzie (n. d.) recommends that sites be visited multiple times to produce reliable estimates. More specifically, MacKenzie recommends sampling so that there is "a 70% chance of detecting [the species] at least once." From our Jagger Museum samples this criterion was achieved for House Sparrow and probably would have been achieved for Japanese White-eye given a larger sample size (naïve frequency of occurrence >0.6). The other species (Hawai`i `Amakihi, Erckel's Francolin, House Finch and Saffron Finch [*Sicalis flaveola*]) were observed only once at Jagger Museum yielding naïve frequency of occurrence of 0.33, and require additional repeated sampling (>5 occasions) to calculate reliable detection probabilities.

Density

We estimated densities (birds/ha) for species with adequate sample sizes (Hawai`i `Amakihi, Japanese White-eye, and House Finch).

Hawai`i `Amakihi

Hawai`i `Amakihi were absent in barren habitats, and their densities increased with increasing habitat physiognomy. That is, densities in shrubland/ grassland (0.0717 birds/ha; 95% CI 0.0163 – 0.3157) were less than densities in woodland (0.4829 birds/ha; 95% CI 0.1429 – 1.6322), a six-fold increase. A half-normal key model was selected over other models because it was more parsimonious (Appendix G); however, all Akaike's Information Criteria (AIC) values were within 4 units.

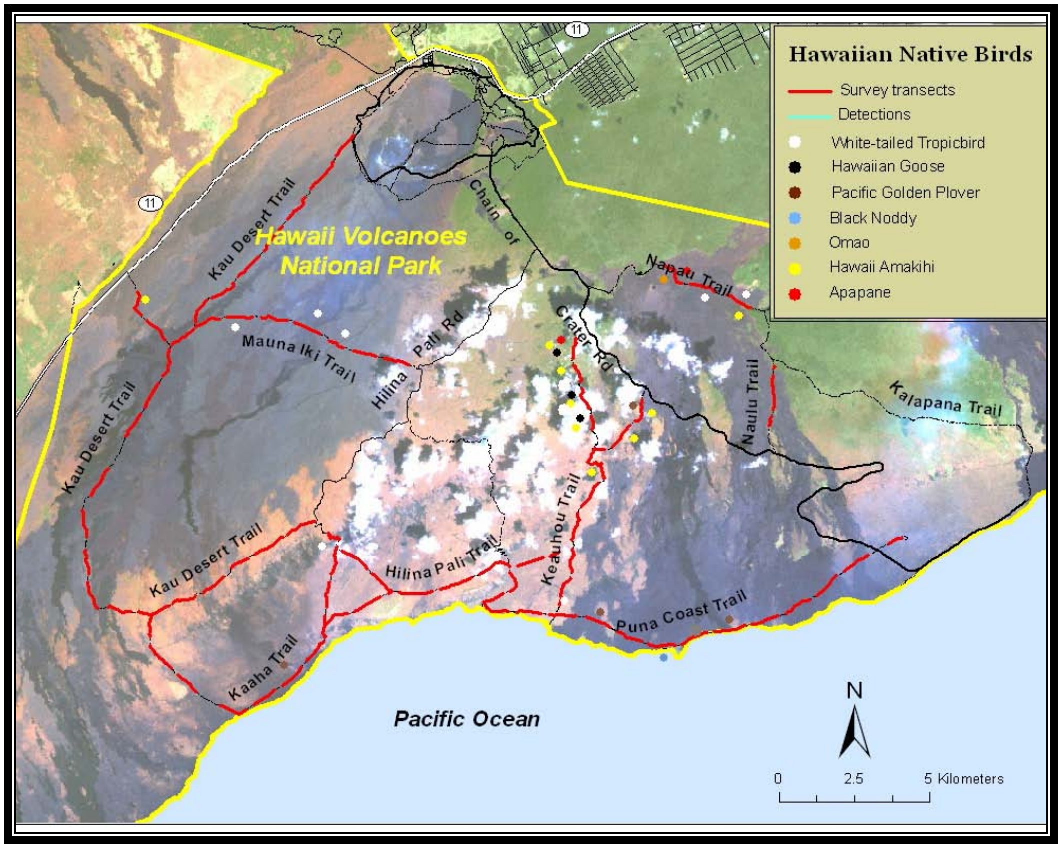

Figure 4. Distribution of native birds detected during line transect surveys, Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.

Japanese White-eye

Japanese White-eye densities increased with habitat physiognomy. We estimated densities of 0.0069 birds/ha (95% CI 0.0013 – 0.0364), 0.0953 birds/ha (95% CI 0.0297 – 0.3052), and 0.8673 birds/ha (95% CI 0.3208 – 2.3452) in barren, shrubland/ grassland, and woodland habitats, respectively. A hazard-rate key model was selected over other models because it possessed the lowest AIC, although other parameters slightly exceeded threshold limits, and because the hazard-rate model can have a nearly flat detection shoulder for some distance from the point (Appendix H). Variance estimate and confidence interval for barren habitat may not be reliable because of a single observation.

House Finch

House Finch densities followed a pattern similar to Hawai`i `Amakihi. That is, House Finch were not detected in barren habitats, and their densities increased with habitat physiognomy. House Finch densities were 0.0915 birds/ha (95% CI 0.0546 – 0.1536) in shrubland/ grassland habitat and 0.1580 birds/ha (95% CI 0.0868 – 0.2873) in woodland habitat. A uniform key model with a single cosign adjust term was selected over other models because parameters were within threshold limits (Appendix I). All AIC values were within 4 units.

Sampling Effort

We used the species- and habitat-specific CV values from our density estimation procedures ($CV_o\left(\hat{D}\right)$; Table 4) to determine the total number of transects (km) needed to produce CV values of 10%, 20%, and 50% (Table 5). Variability in density estimates strongly influenced the total number of transects required to achieve three levels of CV; where species with low precision (i.e., high $CV_o\left(\hat{D}\right)$ values) require substantially more sampling than less variable species, especially in habitats occupied at low density (e.g., barren habitat type).

Table 4. *Observed* $CV_o\left(\hat{D}\right)$ *values by species for three lowland habitats, Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.*

	Habitat Type		
Species	**Barren**	**Shrubland**	**Woodland**
Hawai`i `Amakihi	146.38	84.97	61.41
Japanese White-eye	95.43	63.21	49.09
House Finch	54.49	26.21	28.28

Table 5. *Total transect length (km) needed to produce density estimates with three levels of CV (10%, 20%, and 50%), Hawai`i Volcanoes National Park, 14 April - 14 July, 2005.*

	Habitat Type		
CV	**Barren**	**Shrubland**	**Woodland**
Hawai`i `Amakihi			
10%	5,143	3,393	490
20%	1,286	848	123
50%	206	136	20
Japanese White-eye			
10%	2,186	1,878	313
20%	546	469	78
50%	87	75	13
House Finch			
10%	713	323	104
20%	178	81	26
50%	29	13	4

Producing precise densities (10% CV) for the three species requires substantial sampling, regardless of the habitat (>100 km of transects; Table 5). This is especially true for Hawai`i `Amakihi in the open habitats (i.e., barren and shrubland habitats) where >3,000 km of transects are required. In contrast, density estimates with low precision (50% CV) require less sampling (<100 km of transects), although more is needed for Hawai`i `Amakihi than for Japanese White-eye or House Finch.

Focal Partridge Search

We failed to detect any Close-barred Francolin in 30 hours of surveying four AS sites of two hectares each and four kilometers of LT at `Āinahou Ranch. Furthermore, no incidental detections were made in the additional five hours we spent at `Āinahou Ranch. Therefore, we used the *EDD* for Erckel's Francolin (Scott et al. 1986), assuming that the Close-barred Francolin should have been readily observed (p=0.8; Reed 1996). The number of visits necessary to statistically conclude that the Close-barred Francolin is extirpated is 3.3 visits, or slightly more than 13 hours of surveying (N_{min}=3.322). From this, we tentatively conclude that the Close-barred Francolin is no longer present in HAVO with 99% confidence. However, the Close-barred Francolin detection probability may be substantially less than that of Erckel's Francolin because of low density, patchy distribution, species cryptic behavior, detection hindered by tall, dense grass, and surveyor presence. Assuming that Close-barred Francolin detection probability is p=0.20, and all other variables held constant, then 20.6 visits, or 83 hours of surveys, would be needed to conclude the species is no longer present in HAVO with 99% certainty.

DISCUSSION

Previous Surveys of HAVO Lowlands

Lowland regions of HAVO have previously been surveyed (Baldwin 1940; Dunmire 1962; Banko and Banko 1979; Conant 1980), and the survey areas coincident with our study include the `Āinahou and Hilina Pali areas. The survey methods used among these studies differed sufficiently to preclude direct comparisons; however, several changes have occurred in the lowland bird community (Appendix J). In Baldwin's census in HAVO, he conducted a modified form of line transect survey. Baldwin walked along 183 m transects, taking short excursions perpendicular to the transect when necessary, randomly stopping to observe for six to eight minutes. Dunmire walked along trails in loop fashion, avoiding repeating the same tract in a day, with average survey times lasting 2½ hours a day. Banko and Banko surveyed 366 m transects including all birds seen within 30 m and heard within 60 m of either side of the transect. Conant used two distance sampling methods to detect birds, the ad hoc transect method (Emlen 1971) and point transect (also called variable circular plot) method.

Species not detected in our survey but found in similar habitat in previous surveys include: Hawaiian Hawk (*Buteo solitarius*), Chukar (*Alectoris Chukar*), Ring-necked Pheasant (*Phasianus colchicus* ssp.), Green Pheasant (*Phasianus colchicus versicolor*), Mongolian Pheasant (*Phasianus colchicus monolicus*), Close-barred Francolin, California Quail (*Callipepla californica*), Bristle-thighed Curlew (*Numenius tahitiensis*), Hawaiian Owl (*Asio flammeus*), Hawaiian Crow (*Corvus hawaiiensis*), `Elepaio (*Chasiempis sandwichensis*), Red-billed Leiothrix (*Leiothrix lutea*), `O`u (*Psittirostra psittacea*), Hawai`i Creeper (*Oreomystis mana*), Hawai`i `Akepa(*Loxops coccineus coccineus*), and `I`iwi (*Vestiaria coccinea*). Although no attempt was made to confirm the presence of these species through other sources, we expect the Hawaiian Hawk, California Quail and Hawaiian Owl to be present in the habitats inventoried. In addition, we did not attempt to calculate the extinction probability of these species within the low elevation portions of the park, except for the Close-barred Francolin (see below).

Avian Disease in Lowlands

Native birds in low elevation Hawai`i have several large obstacles impeding their success. The non-native mosquito *Culex quinquefasciatus* is a vector for avian malaria, one of the factors responsible for the extreme reduction in populations of native birds in lowland areas of Hawai`i (Warner 1968). A recent study in the Puna district, adjacent to HAVO, however, shows that the population size of Hawai`i `Amakihi is increasing (Woodworth et al. 2005). Woodworth et al. suggest that lowland Hawai`i `Amakihi have developed resistance to avian malaria that can be passed to offspring, allowing repopulation of the lowlands of Hawai`i. Our findings show `amakihi were the most abundant of native birds in the park lowlands and were found as low as 620 m.

Focal Partridge Search

The Close-barred Francolin was introduced at `Āinahou Ranch in 1957 (Hawai`i Audubon Society 1997). When introduced, the francolin showed signs of successful breeding, and reports of the birds were never far from the ranch house (see Conant 1980). Two of these francolins were observed visually in August 2004 from Friends of `Āinahou volunteers (R. Pyle, personal communications, 2 October 2005). In our surveys of `Āinahou Ranch we found no evidence of francolins. In addition to our surveys, `Āinahou Ranch is visited daily by employees of the nēnē breeding project. Previous to our survey, a separate project mist-netted and banded birds in this same vicinity. Considering the fact that multiple experienced birders consistently visit `Āinahou, we can assume that the Close-barred Francolin is absent from the ranch area. Potentially, the francolin is now extinct in HAVO. This conclusion is based on a generous detection function. It could be that the Close-barred Francolin detection function is low; therefore, additional surveys will be needed to confidently conclude the species is extirpated in HAVO.

Inventory and Future Monitoring

We observed more than 80% of the bird species expected to inhabit lowland areas of HAVO. This falls short of our first objective of observing 90% of the lowland birds. Our estimator of species richness, however, is conservative (Krebs 1989). That is, the estimator tends to overestimate the number of species in the bird assemblage, thereby underestimating the proportion of birds observed in relation to the predicted total assemblage. Assemblages comprised predominantly of rare species may be overestimated, where rarity can be because the species have low probabilities of detection or occur at few sites. Therefore, it is likely that we observed closer to the desired 90% of species that occupy sites we sampled with AS methods, and probably more than 90% of the species in LT sampled woodland, shrubland/ grassland and barren habitats. Additional surveys with the sole objective of inventorying lowland birds in HAVO are not necessary at this time. However, monitoring the bird community assemblage should be included as an objective in further surveys to document new species to the park and track persistence of species already present (see potential alien invasions below).

We used survey methods that allowed us to determine both abundance and distribution throughout lowland HAVO, our second objective. The most ubiquitous species in our study were observed at less than half the sites and transects, and these were non-native species. Most species were observed at only a few sites or transects and usually only one or a few individuals were detected (Table 3). This pattern was observed for both native and non-native birds.

Lastly, we sought to provide baseline information necessary to develop a monitoring plan for lowland birds. Although we knowingly under-sampled the AS site (Jagger Museum), we can deduce some information from the data regarding potential detection probabilities. For species that are conspicuous and portray high site fidelity (e.g., House Sparrow) the detection probability most likely is high, and false absences are a relatively minor concern (the amount of bias is low compared to estimate variability). False absences may have a greater effect on site occupancy for species that are detected less reliably and naïve frequency of occurrence estimates may be negatively biased, which would result in an underestimation of site occupancy (i.e., the species is more widespread than ascertained). From our limited data set, we would expect this bias for most of the species observed during AS surveys (see Table 3).

If site occupancy is used to monitor lowland birds, a majority of sampling sites will need to be visited multiple times (>5 repeated sampling occasions) to produce reliable estimates at all of our AS sites (see MacKenzie n. d.). Moreover, additional unaltered use sites should be identified and sampled to equalize the number of sites in each use category (i.e., increase from three to approximately 15-20 sites). We recommend that the AS sampling be expanded from attraction sites to a sampling grid (see Sauer et al. 1995 and Ralph et al. 1995 for justification and design guidelines). In addition, we suggest that density estimation methods be employed with Percent Area Occupied (PAO) sampling. Changes in both range and abundance could then be monitored simultaneously and trends identified. A grid based PAO sampling scheme would facilitate identifying species' ranges and increase density estimate precision.

The precision of density estimates decreased from relatively precise in woodland habitats, to moderate in shrubland habitats, to poor in barren habitats. It is unrealistic to expect that sufficient sampling could be allocated to barren habitats to produce precise population densities, that is, density estimates with CV < 50%. If future monitoring requires statistical inference for the entire park, then some level of sampling must be allocated to each habitat type in the park. Thus, a small number of transects are required in the barren habitats; however, these data may be more useful for species presence and absence then for density estimation. The same limitations apply to shrubland habitat, but to a lesser extent. Species that occur in shrubland habitat in low densities, Hawai`i `Amakihi and Japanese White-eye, for example, still require substantial survey effort to produce precise density estimates. Producing moderately precise estimates for House Finch, a species that readily inhabits open vegetated habitats, could be accomplished with less than 100 km of transects within shrubland habitat. Between 100 and 500 km of transects would be required to produce precise density estimates for all three species in woodland habitat, or moderately precise density estimates could be obtained from as little as 25 to 125 km of transects within woodland habitat.

Synopsis of Lowland Birds in HAVO

Landscape of HAVO

One of the aspects of HAVO that makes it home to a diverse bird community is the varied landscapes across the park. The land ranges from dry, sandy desert to barren lava to grasslands and wet `ōhi`a rainforest. Dry lava landscapes are inhospitable to birds, and the bird numbers increase 100-fold as land cover changes from dry barren to wet forest (Gorresen et al. in press). Throughout the lowlands, the introduction (and since removal) of goats significantly degraded the landscape. The once native grasses, vines, and woody plants of the lowlands were browsed on until there was just barren rock in some areas (Mueller-Dombois and Spatz 1972). The vegetation that once supported native birds in the lowland region of HAVO is now better habitat for alien birds due to lava flows, fire, and destruction by goats (Mueller-Dombois and Spatz 1972; Pratt 1994; this study).

Birds of Prey

The raptor and owls that have been found in the park include the Hawaiian Hawk, Hawaiian Owl, and Barn Owl (*Tyto alba*; Baldwin 1940, 1941; Dunmire 1962, Banko and Banko 1979, Conant 1980). Ours is the first survey in the park to find the Barn Owl, and we did not detect the endangered Hawaiian Hawk and the native Hawaiian Owl. Both owls prefer grassland and prey on rodents, which are available in HAVO lowlands. The Hawaiian Hawk feeds on rodents, insects, and birds in most habitats across the island. It is possible that the Barn Owl has displaced the Hawaiian Owl in the park, although there is no data to evaluate this possibility, and the Hawaiian Owl may have been missed due to its behavioral habits.

Game Birds

The surveys in HAVO show the gallinaceous bird diversity has changed significantly over the last 75 years (Baldwin 1940, 1941). In the past surveys, four types of pheasants, two species of francolins, the Chukar, and the California Quail were all detected (Baldwin 1940, 1941; Dunmire 1962, Banko and Banko 1979, Conant 1980). Of these birds, we found Erckel's Francolin and Kalij Pheasant (*Lophura leucomelanos*). Francolins occupy grassland and open forest, whereas pheasants prefer open forest and clearings. California Quail also favor grassland, and the Chukar lives in mostly inhospitable, rocky habitats. It is possible that the remaining game bird species no longer exist in the HAVO lowlands, however, our study does not provide conclusive evidence to support this claim.

Hawaiian Goose

The Hawaiian Goose (*Branta sandvicensis)* was a rare sighting in the previous surveys, although we observed 29 individuals at three AS sites and on four LT transects. A captive breeding and release program for the Hawaiian Goose was initiated in HAVO subsequent to previous surveys (U.S. Fish & Wildlife 2004); but the population size varies year to year (K. Misajon, pers. comm.).

Potential Alien Invasions

We were interested to find whether species new to the island have colonized HAVO. We found a new species to the park, the Yellow-billed Cardinal (*Paroaria capitata*). This species was observed at the anchialine pools at both Halapē and Keauhou beaches. The Yellow-billed Cardinal is native to South America and was introduced to Hawai`i around 1930 (Pratt 2005). The cardinal is widespread from south Kohala to Pahala.

Relatively new to the park are the non-native Saffron Finches and Yellow-fronted Canaries (*Serinus mozambicus*). The Saffron Finch was first reported within HAVO in January 1999 at Kilauea Military Camp (KMC) (R. Pyle, 2 October 2005). Saffron Finches are native to South America, and were introduced to Hawai`i in 1965 (Berger 1983). This is the first documented status within the park for the Yellow-fronted Canary, although incidental observations have previously been made. Yellow-fronted Canaries are native to Africa and were introduced in 1964 (Berger 1983). Both the Saffron Finch and Yellow-fronted Canary are commonly found along the Kona coast, Hualālai, and South Kohala District (Hawai`i Audubon Society 1997). We observed the Saffron Finch at the KMC lawns and saw both the Saffron Finch and the Yellow-fronted Canary at the Visitor's Center, two highly impacted sites.

Other alien passerines that may become established are the Japanese Bush-warbler (*Cettia diphone*), Northern Mockingbird (*Mimus polyglottos*), Lavender Waxbill (*Estrilda caerulescens*), African Silverbill (*Lonchura cantans*), and Java Sparrow (*Padda oryzivora*). All of these birds are found in other areas of the island in grassland, shrubland, woodland and forest habitats, and have not yet expanded to HAVO. Introduced in the 1930s, the Japanese Bush-warbler is widespread across the island, prefers the dense understory of wet forest or haole koa (*Leucaena leucocephela*), and is considered to be encroaching into HAVO (J. Foster, pers. comm.). There has been an incidental report of a Northern Mockingbird, which favors dry, brushy habitats, in HAVO (Camp et al. 2002, Swift 2005). The Lavender Waxbill is native to Africa, was introduced in the 1960s and is established in the Kona and Kohala districts. African Silverbill have been documented in the park (Camp et al. 2002), are abundant in Kohala and Kona districts, and are usually found in kiawe (*Prosopis pallida*) and grassland. The Java Sparrow is abundant in highly altered urban and open grassy areas on both the wet and dry side of the island.

Native Passerines

Hawai`i Volcanoes National Park is home to many of the remaining native bird species of Hawai`i Island and was historically inhabited by now extinct birds. The majority of the remaining Hawaiian native birds generally persist in wet forest at higher elevations, and although we excluded rainforest from this study, we did detect forest birds in the low elevation dry woodlands.

Although we no longer find many honeycreepers in the lowlands, Hawai`i `Amakihi and Apapane (*Himatione sanguinea*) occur in low-elevation, forested habitats of Hawai`i (Woodworth et al. 2005). The honeycreepers that we did not find in our survey include the `O`u, `Akiapola`au, Hawai`i Creeper (*Oreomystis mana*), Hawaii`Akepa, and `I`iwi, though these were all observed in previous park surveys (Appendix J).  `O`u were historically one of the most abundant honeycreepers throughout the high islands, and were present in low numbers through the `ōhi`a forests of HAVO into the 1970's (Pratt 2005), but is now considered critically endangered and possibly extinct (BirdLife International 2004).  The `Akiapola`au, Hawai`i Creeper, and Hawai`i `Akepa are federally listed endangered species that are now relegated to high elevation forests of Hawai`i Island.  `I`iwi were once found in forest down to the sea (Munro 1960), but are now restricted to higher elevations.

The native crow, Hawaiian Crow, formerly nested in HAVO (Baldwin 1940), and is now extinct in the wild (BirdLife International 2004). We did not detect Hawai`i `Elepaio, a native flycatcher, although they were detected in previous park counts and in similar habitat. This study does not elucidate why `Elepaio were not detected in the low elevation portions of the park.  The native thrush, `Oma`o (*Myadestes obscurus*), was detected on the edge of a wet forest kīpuka.

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APPENDIX A. EXAMPLES OF AREA SEARCH SURVEY SITES

Unaltered site for AS Anchialine pool at Halapē Iki.

Moderately altered site for AS at Pu`uloa Petroglyphs.

Intensely used AS site at Kealakomo Picnic Area.

Area Search site used for focal partridge searches, `Āinahou Corral.

APPENDIX B. CHARACTERISTICS OF THE 38 AREA SEARCH SURVEY SITES

Site Name	Use*	Elevation (m)	Species Detected
`Āinahou Horse Corral	Intense	840	3
`Āinahou Ranch House	Intense	920	8
Alanui Kohiko	Moderate	200	1
`Āpua Pt. Beach	Moderate	0	2
End of COC Rd.	Intense	20	2
Halapē Anchialine Pond	Moderate	0	2
Halapē Anchialine Pond 2	Unaltered	10	1
Halapē Beach	Intense	0	2
Halapē Campground	Intense	0	2
Halapē Iki Beach and Pond	Moderate	0	4
Halapē Shelter and Lua	Intense	40	1
Halema`uma`u	Intense	1,090	1
Hilina Pali Campground	Intense	1,010	1
Hōlei Pali	Moderate	170	1
Hōlei Sea Arch	Intense	10	1
Jagger Museum	Intense	1,240	6
Ka`aha Beach	Moderate	0	1
Kealakomo Picnic Area	Intense	630	1
Keanakāko`i	Moderate	1,110	3
Keauhou Anchialine Pond	Unaltered	0	1
Keauhou Anchialine Pond 2	Unaltered	0	1
Keauhou North Beach	Moderate	0	4
Keauhou Shelter/ Lua	Intense	30	1
Keauhou South Beach	Moderate	0	8
Kīlauea Overlook Parking Lot/Lua	Intense	1,230	4
Kīlauea Overlook Picnic Shelter	Intense	1,230	5
Kīpuka Kahaliki	Moderate	910	3
KMC Cafeteria/Store	Intense	1,220	7
KMC Chapel/Theater	Intense	1,220	6
Lua Manu	Moderate	1,110	2
May 1969 Lava Flow Pullout	Moderate	930	3
Muliwai Pele	Moderate	750	1
Pepeiao Cabin	Moderate	520	1
Pu`uloa	Moderate	40	1
Research Center Parking Lot	Intense	1,180	4
Steam Vents	Intense	1,220	2
Visitors Center	Intense	1,220	9
Volcano House	Intense	1,220	4

*Use designations are defined in Table 1.

APPENDIX C. EXAMPLES OF LINE TRANSECT SURVEY SITES

Trail designated as barren lava, Puna Coast Trail.

Trail designated as shrubland/ grassland, Ka`ū Desert Trail.

Trail assigned as barren lava, although grass is present, Ka’aha Trail.

Trail designated as woodland, Keauhou Trail.

APPENDIX D. CHARACTERISTICS OF THE 84 LINE TRANSECTS

Transect Name	Habitat Type[a]	Elevation (m)	Species Detected
\`Āinahou 1	W	940	8
\`Āinahou 2	W	880	7
\`Āinahou 3	W	820	10
\`Āinahou 4	S	760	6
Footprints 1	W	910	4
Footprints 2	S(B)	900	3
Halapē 1	S	30	1
Halapē 2	S	110	0
Halapē 3	S	180	0
Hilina Pali 1	S	260	0
Hilina Pali 2	S	260	3
Hilina Pali 3	S	250	3
Hilina Pali 4	S	290	3
Hilina Pali 5	S	230	2
Hilina Pali Overlook 1	S	380	2
Hilina Pali Overlook 2	S	240	0
Hilina Pali Overlook 3	S	150	0
Hilina Pali Overlook 4	S	80	1
Hilina Pali Overlook 5	S	110	0
Hilina Pali Overlook 6	S	200	0
Ka\`aha 1	S(B)	20	0
Ka\`aha 2	B	20	1
Ka\`aha 3	B	20	1
Ka\`aha 4	B	40	1
Ka\`aha 5	B	200	0
Ka\`aha 6	S	380	0
Ka\`aha 7	W	500	2
Ka\`ū Desert 1	W	1,170	3
Ka\`ū Desert 2	S	1,130	0
Ka\`ū Desert 3	S(B)	1,070	0
Ka\`ū Desert 4	B	1,020	3
Ka\`ū Desert 5	S(B)	990	1
Ka\`ū Desert 6	S	950	1
Ka\`ū Desert 7	B(S)	930	1
Ka\`ū Desert 8	B(S)	910	0
Ka\`ū Desert 9	S(B)	900	0
Ka\`ū Desert 10	S(B)	850	0
Ka\`ū Desert 11	S(B)	820	0
Ka\`ū Desert 12	S(B)	760	0
Ka\`ū Desert 13	B(S)	710	1
Ka\`ū Desert 14	W(S)	650	1
Ka\`ū Desert 15	W	600	2
Ka\`ū Desert 16	S	550	1
Ka\`ū Desert 17	W(S,B)	540	6
Ka\`ū Desert 18	W	550	5
Ka\`ū Desert 19	S	560	2
Ka\`ū Desert 20	S	610	3
Ka\`ū Desert 21	S(W)	650	1
Ka\`ū Desert 22	W	700	2

Transect Name	Habitat Type[a]	Elevation (m)	Species Detected
Keauhou 1	W	760	4
Keauhou 2	W	700	3
Keauhou 3	W	660	2
Keauhou 4	S	510	3
Keauhou 5	S	380	1
Keauhou 6	S	280	1
Keauhou 7	S	220	2
Keauhou 8	S	200	1
Keauhou 9	S	70	3
Mauna Iki 1	S	970	2
Mauna Iki 2	S	970	1
Mauna Iki 3	S	950	1
Mauna Iki 4	B	950	1
Mauna Iki 5	B	960	0
Mauna Iki 6	B	940	1
Mauna Iki 7	B	930	0
Nāpau 1	W(B)	970	2
Nāpau 2	B	960	1
Nāpau 3	B	880	3
Nāulu 1	S(B)	710	1
Nāulu 2	S(B)	760	2
Nāulu 3	S(B,W)	780	1
Puna Coast 1	S	20	1
Puna Coast 2	S	20	1
Puna Coast 3	S	30	3
Puna Coast 4	B	20	3
Puna Coast 5	S(B)	20	0
Puna Coast 6	B	10	2
Puna Coast 7	B	10	1
Puna Coast 8	B(S)	10	3
Puna Coast 9	B(S)	10	0
Puna Coast 10	B	20	0
Puna Coast 11	B	30	0
Puna Coast 12	S(B)	40	0
Pu`uloa	S	40	2

[a]Habitat type (W-woodland, S-shrubland/ grassland, B-barren lava) was assigned to each transect. Additional habitat types that the transect traversed is presented in parenthesis.

APPENDIX E. DESCRIPTION OF DATA RECORDED FOR TRANSECTS AND BIRD OBSERVATIONS

Time: Start and End, sampling occurred between one-half hr before and 4 hrs post sunrise.
Habitat Code: As delineated by Jacobi (1989).
Temperature, Wind average and maximum: using Kestrel Pocket Meter. If wind exceeded 14mph, the survey was stopped until wind subsided.
Cloud cover: 0-10, estimated to the nearest 10%
Rain: 0-4 scale, 0 being no rain, 4 being heavy rain. If rain exceeded category 3, the survey was stopped until rain subsided.
Waypoint: Using GPS76c, UTM zone 5N
GPS coordinates: The x,y coordinates were documented to back up the waypoints taken.

Data recorded when a bird was detected:
Bird Species: Using species codes derived from the Breeding Bird Lab of Cornell, some codes adapted or created for Hawaiian birds, using same nomenclature system.
Sex: As determined by song or plumage (male, female, or unknown)
Distance: Measured with Bushnell Yardage Pro Trophy Rangefinders, recorded to meter
Detection Type: 1= audial, 2= visual, 4= audial, then visual, 8= seen along trail, not on transect, 9= heard along trail, not on transect
Azimuth of the Trail: Taken with compass, recorded to nearest single degree.
Azimuth to the Bird: Taken with compass, recorded to nearest single degree.
Waypoint: Using GPS76c, UTM zone 5N
Time of Observation
Disturbed by Observer (Yes/No)
Flyover (Yes/No)
Number of Individuals
Direction of Flight (if disturbed): recorded to the nearest degree.

APPENDIX F. LIST OF SPECIES KNOWN TO INHABIT OR REGULARLY VISIT HAWAI`I ISLAND (PYLE 2002)

Species Name	Scientific Name	Origin
Laysan Albatross	*Phoebastria immutabilis*	Indigenous
Dark-rumped Petrel	*Pterodroma phaeopygia*	Indigenous
Bulwer's Petrel	*Bulweria bulwerii*	Indigenous
Band-rumped Storm-petrel	*Oceanodroma castro*	Indigenous
White-tailed Tropicbird	*Phaethon lepturus*	Indigenous
Red-tailed Tropicbird	*Phaethon rubricauda*	Visitor
Brown Booby	*Sula leucogaster*	Indigenous
Great Frigatebird	*Fregata minor*	Indigenous
Cattle Egret	*Bubulcus ibis*	Alien
Black-crowned Night-heron	*Nycticorax nycticorax*	Indigenous
Cackling Goose	*Branta hutchinsii*	Visitor
Hawaiian Goose	*Branta sandvicensis*	Endemic
Muscovy Duck	*Cairina moschata*	Alien
American Wigeon	*Anas Americana*	Visitor
Mallard Duck	*Anas platyrhynchos*	Alien
Hawaiian Duck	*Anas wyvilliana*	Endemic
Northern Shoveler	*Anas clypeata*	Visitor
Northern Pintail	*Anas acuta*	Visitor
Green-winged Teal	*Anas crecca*	Visitor
Ring-necked Duck	*Aythya collaris*	Visitor
Lesser Scaup	*Aythya affinis*	Visitor
Hawaiian Hawk	*Buteo solitarius*	Endemic
Chukar	*Alectoris Chukar*	Alien
Gray Francolin	*Francolinus poolicerianus*	Alien
Close-barred Francolin	*Francolinus adspersus*	Alien
Black Francolin	*Francolinus francolinus*	Alien
Erckel's Francolin	*Francolinus erckelii*	Alien
Japanese Quail	*Coturnix japonica*	Alien
Red Junglefowl	*Gallus gallus*	Alien
Kalij Pheasant	*Lophura leucomelanos*	Alien
Ring-necked Pheasant	*Phasianus colchicus*	Alien
Common Peafowl	*Pavo cristatus*	Alien
Wild Turkey	*Meleagris gallopavo*	Alien
California Quail	*Callipepla californica*	Alien
Gambel's quail	*Callipepla gambelii*	Alien
Common Moorhen	*Gallinula chloropus*	Indigenous
Hawaiian Coot	*Fulica alai*	Indigenous
Pacific Golden-plover	*Pluvialis fulva*	Indigenous
Black-necked Stilt	*Himantopus mexicanus*	Indigenous
Wandering Tattler	*Heteroscelus incanus*	Visitor
Bristle-thighed Curlew	*Numenius tahitiensis*	Visitor
Ruddy Turnstone	*Arenaria interpres*	Visitor
Sanderling	*Calidris alba*	Visitor

Species Name	Scientific Name	Origin
Dunlin	*Calidris alpina*	Visitor
Long-billed Dowitcher	*Limnodromus scolopaceus*	Visitor
Laughing Gull	*Larus atricilla*	Visitor
Ring-billed Gull	*Larus delawarensis*	Visitor
Black Noddy	*Anous minutus*	Indigenous
Chestnut-bellied Sandgrouse	*Pterocles exustus*	Alien
Rock Dove	*Columba livia*	Alien
Spotted Dove	*Streptopelia chinensis*	Alien
Zebra Dove	*Geopelia striata*	Alien
Mourning Dove	*Zenaida macroura*	Alien
Rose-ringed Parakeet	*Psittacula krameri*	Alien
Barn Owl	*Tyto alba*	Alien
Hawaiian Owl	*Asio flammeus*	Indigenous
Hawaiian Crow	*Corvus hawaiiensis*	Endemic
Hawai`i `Elepaio	*Chasiempis sandwichensis*	Endemic
Skylark	*Alauda arvensis*	Alien
Japanese Bush-warbler	*Cettia diphone*	Alien
`Oma`o	*Myadestes obscurus*	Endemic
Hwamei	*Garrulax canorus*	Alien
Red-billed Leiothrix	*Leiothrix lutea*	Alien
Japanese White-eye	*Zosterops japonicus*	Alien
Northern Mockingbird	*Mimus polyglottos*	Alien
Common Myna	*Acridotheres tristis*	Alien
Saffron Finch	*Sicalis flaveola*	Alien
Yellow-billed Cardinal	*Paroaria capitata*	Alien
Northern Cardinal	*Cardinalis cardinalis*	Alien
House Finch	*Carpodacus mexicanus*	Alien
Yellow-fronted Canary	*Serinus mozambicus*	Alien
`O`u	*Psittirostra psittacea*	Endemic
Palila	*Loxioides bailleui*	Endemic
Hawai`i `Amakihi	*Hemignathus virens*	Endemic
`Akiapola`au	*Hemignathus munroi*	Endemic
Hawai`i Creeper	*Oreomystis mana*	Endemic
Hawai`i `Akepa	*Loxops coccineus*	Endemic
`I`iwi	*Vestiaria coccinea*	Endemic
Apapane	*Himatione sanguinea*	Endemic
House Sparrow	*Passer domesticus*	Alien
Red-cheeked Cordonbleu	*Uraeginthus bengalus*	Alien
Lavender Waxbill	*Estrilda caerulescens*	Alien
Black-rumped Waxbill	*Estrilda troglodytes*	Alien
Red Avadavat	*Amandava amandava*	Alien
African Silverbill	*Lonchura cantans*	Alien
Nutmeg Mannikin	*Lonchura punctulata*	Alien
Java Sparrow	*Padda oryzivora*	Alien

Appendix G. Hawai`i `Amakihi Model Parameters and Density Estimates Calculated from Line Transect Surveys

Analysis	Model [1]	Adjusters [1]	Truncation	No. Birds	No. Param.	H(0) %CV	$\text{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting											
	H-norm	None	181.0 m	74	1	4.15	0.80	-	654	48.811	4.15
			40.1 m[2]	63	1	13.07	6.2	-	464	32.652	13.07
	H-rate	None			2	14.65	7.7	0.02	466	33.716	14.65
		Cos[3]									
	H-norm	H-poly[3]									
	Unif	Cos[3]									
	Unif	S-poly[3]									
Final Model											
	H-norm	None	40.1 m	63	1	13.07	6.2	-	464	32.652	13.07

[1] Model codes: H-norm = Half-normal detection function; H-rate = Hazard-rate detection function; Unif = Uniform detection function; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hermite polynomial expansion term.
[2] Selected truncation level.
[3] Model failed to converge or parameters were constrained or bounded.

APPENDIX H. JAPANESE WHITE-EYE MODEL PARAMETERS AND DENSITY ESTIMATES CALCULATED FROM LINE TRANSECT SURVEYS

Analysis	Model [1]	Adjusters [1]	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting											
	H-norm	None	163.5 m	113	1	4.77	2.4	-	1043	61.173	4.77
			73.0 m[2]	96	1	6.02	2.9	-	762	32.573	6.02
	H-rate	None			2	11.53	10.0	0.75	749	30.154	11.53
		Cos[3]									
	H-norm	H-poly[3]									
	Unif	Cos[3]									
	Unif	S-poly[3]									
Final Model											
	H-rate	None	73.0 m	96	2	11.53	10.0	0.75	749	30.154	11.53

[1] Model codes: H-norm = Half-normal detection function; H-rate = Hazard-rate detection function; Unif = Uniform detection function; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hermite polynomial expansion term.
[2] Selected truncation level.
[3] Model failed to converge or parameters were constrained or bounded.

APPENDIX I. HOUSE FINCH MODEL PARAMETERS AND DENSITY ESTIMATES CALCULATED FROM LINE TRANSECT SURVEYS

Analysis	Model [1]	Adjusters [1]	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting											
	H-norm	None	290.6 m	81	1	5.11	6.7	-	836	105.04	5.11
			95.2 m[2]	65	1	10.93	21.5	-	569	51.177	10.93
	H-rate	None			2	12.38	25.9	0.75	570	55.560	12.38
		Cos[3]									
	H-norm	H-poly[3]									
	Unif	Cos 1			1	6.18	8.0	-	569	51.131	6.18
	Unif	S-poly 2			1	3.39	2.6	-	570	61.997	3.39
Final Model											
	Unif	Cos 1	95.2 m	65	1	6.18	8.0	-	569	51.131	6.18

[1] Model codes: H-norm = Half-normal detection function; H-rate = Hazard-rate detection function; Unif = Uniform detection function; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hermite polynomial expansion term.
[2] Selected truncation level.
[3] Model failed to converge or parameters were constrained or bounded

APPENDIX J. SPECIES COMPARISON BETWEEN PREVIOUS SURVEYS WITHIN HAVO BOUNDARIES, INCLUDING RAINFOREST

Species marked with -- represent suitable habitat that was not surveyed. Species marked with † represent anectodal reports. The * represents an undetermined species of pheasant reported. Blank spaces represent no species detected. The surveys were conducted by Baldwin (1940, 1941), Dunmire (1962), Banko and Banko (1979), Conant (1980), and Turner et al. (2005).

Species	1940-1941	1962	1979	1980	2005
White-tailed Tropicbird	X				X
Hawaiian Goose	X	X	X	†	X
Hawaiian Hawk	X	X	X	X	
Chukar		X			
Erckel's Francolin			X	X	X
Close-barred Francolin				†	
Kalij Pheasant					X
Ring-necked Pheasant	X	*	*	X	
Japanese Green Pheasant	X			X	
Mongolian Pheasant	X				
California Quail	X	X	X	X	
Pacific Golden-plover	X	X	X	X	X
Wandering Tattler		--	--	--	X
Bristle-thighed Curlew	X	--	--	--	
Ruddy Turnstone	X	--	--	--	X
Black Noddy	X	--	--	X	X
Spotted Dove	X	X	X	X	X
Zebra Dove				X	X
Barn Owl					X
Hawaiian Owl	X	X		X	
Hawaiian Crow	†				
Hawai`i `Elepaio	X	X	X	X	--
Skylark	X	X		X	X
`Oma`o	X	X	X	X	X
Hwamei	X	X		X	X
Red-billed Leiothrix	X	X	X		
Japanese White-eye	X	X	X	X	X
Common Myna	X	X	X	X	X
Saffron Finch					X
Yellow-billed Cardinal					X
Northern Cardinal		X	X	X	X
House Finch	X	X	X	X	X
Yellow-fronted Canary					X
`O`u	X	X			
Hawai`i `Amakihi	X	X	X	X	X
`Akiapola`au	X				--
Hawai`i Creeper	X	X			--
`Akepa	†				--

Species	1940-1941	1962	1979	1980	2005
`I`iwi	X	X	X		--
Apapane	X	X	X	X	X
House Sparrow	X	--	--	X	X
Nutmeg Mannikin	X	X	X	X	X